4.2.9.FLIR Resolution

4.2.9.1.Purpose

The purpose of this test is to qualitatively and quantitatively assess the cutoff spatial frequency, minimum resolvable temperature differential, airspeed versus spatial frequency response and the line of sight jitter of the FLIR.

4.2.9.2.General

The FLIR resolution quantitative test involves a combined ground and airborne procedure that dictates the measurement of four separate performance parameters simultaneously. The parameters include the cutoff spatial frequency, minimum resolvable temperature differential, line of sight jitter and airspeed versus spatial frequency response. This test procedure requires more instrumentation and ground support than any other test of this book. For this reason, a qualitative procedure, using a minimum of assets is also provided. In keeping with the stated goal of testing with a minimum of expense, instrumentation and flight time, the qualitative assessment is performed first. If problems are noted, the entire quantitative test procedure is then performed to support the qualitative assessment with measured parameters.

The ground procedure requires the use of a collimator with a heated bar target. The collimator is a device designed to make a small ground target appear to the FLIR as if it were a larger target at a much greater distance. Figure 17 [Ref. 37: p.4.49a] depicts a typical collimator/bar target combination. The assembly consists first of a temperature controlled block which can be varied in temperature from -20° to +20° centigrade at approximate steps of 0.2° centigrade. The temperature is measured by a radiometer to an accuracy of about 0.05° centigrade. In front of the temperature controlled block is placed a template of equally spaced and equal sized slots and bars. The template is made of aluminum and approximates ambient temperature. The spatial frequency response of the target is varied by placing different sized templates on the collimator. Next is a planer mirror used to fold the IR path onto the parabolic mirror. It is the nature of a parabolic mirror that light emanating from the focal point of the mirror is reflected outward along parallel lines. The template is located at the focal point of the mirror. It is this feature which makes the target appear as if it were at a great distance. The parabolic mirror directs the IR onto the FLIR reticle. The spatial frequency of the target is approximated by the equation below. [Ref. 37: pp. 4.48-4.49].

$$SF_t=\frac{FL_c}{W_{1c}} \tag{30}$$

SF_t=spatial frequency of the target
FL_c=focal length of the collimator (folded path length from target to mirror)
W_{1c}=width of one bar and one space in target template

The airborne quantitative procedure requires the use of a full size target consisting of alternating heated and non-heated panels. Figure 18 [Ref. 37: p. 4.46b] shows a sample ground target. Note that many other targets, using both active and/or passive elements, are available at various facilities.

Rather than changing the shape of the panels, the aircraft is flown towards the target to provide a change in the spatial frequency. The temperature differential of the bars is controlled within a window of from 0.5° to 10° centigrade. The temperature is then measured to about 0.05° centigrade accuracy using a radiometer. For the airborne target, the spatial frequency of the target at a given range from the target becomes: [Ref. 37: pp. 4.46-4.47].

$$SF_t=\frac{R_t}{W_{1c}} \tag{31}$$

R_t=range from the target

The range between the aircraft and the ground bar target can be supplied by one of two methods. Typically, a ground based radar is used to provide space positioning data on the test aircraft. This is then time correlated with observations made within the aircraft to determine range to the target at the times of interest. [Ref. 37: pp. 4.46-4.47]. This method requires extensive range radar instrumentation. An alternative, and less costly option, is available if an air to ground radar is available within the test aircraft capable of tracking the IR target. Range is derived from the radar as FLIR observations are made. The sample test procedure described below uses the range radar derived space positioning data.

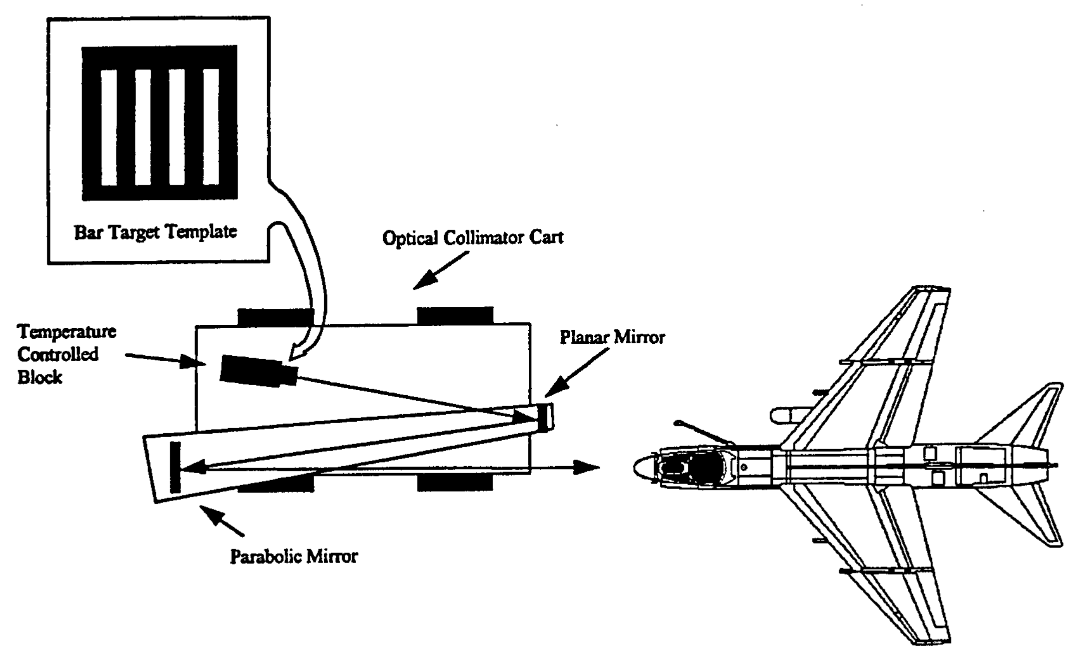


Figure 17: Typical Collimator/Bar Target Combination [Ref. 39:p.4.49a]

Minimum resolvable temperature differential (MRΔT) is the FLIR equivalent of radar minimum signal to noise ratio. MRΔT is a function of the characteristics of the target, background clutter, transmittance of the atmosphere, range to the target, characteristics of the sensor and the signal to noise necessary for desired levels of detection versus false alarms. Additionally, MRΔT is affected by less quantitized variables such as the dwell time in a scanning system, optical resolution, signal processing inaccuracies and display effects. The large number of variables, some of which are not easily measured, requires empirical testing to determine a value for MRΔT. [Ref. 37: pp. 3.15-3.19].

The cutoff spatial frequency is a measure of the angular resolution of the FLIR. Real FLIR cutoff spatial frequencies are limited by a number of effects including optical aberrations, diffraction effects, the detection element field of view, electronic effects and display limitations. These effects are present during ground testing with a stationary FLIR. [Ref. 37: pp. 3.22-3.23]. Additionally, LOS jitter affects the cutoff spatial frequency of an airborne FLIR and is caused by airframe vibrations and other sources of LOS instabilities. [Ref. 37: p. 3.24]. LOS jitter effects can thus be measured indirectly by determining the cutoff spatial frequency on the ground and then in the air and comparing the two. Figure 19 [Ref. 37: p. 4.28b] is an empirically derived plot of ground

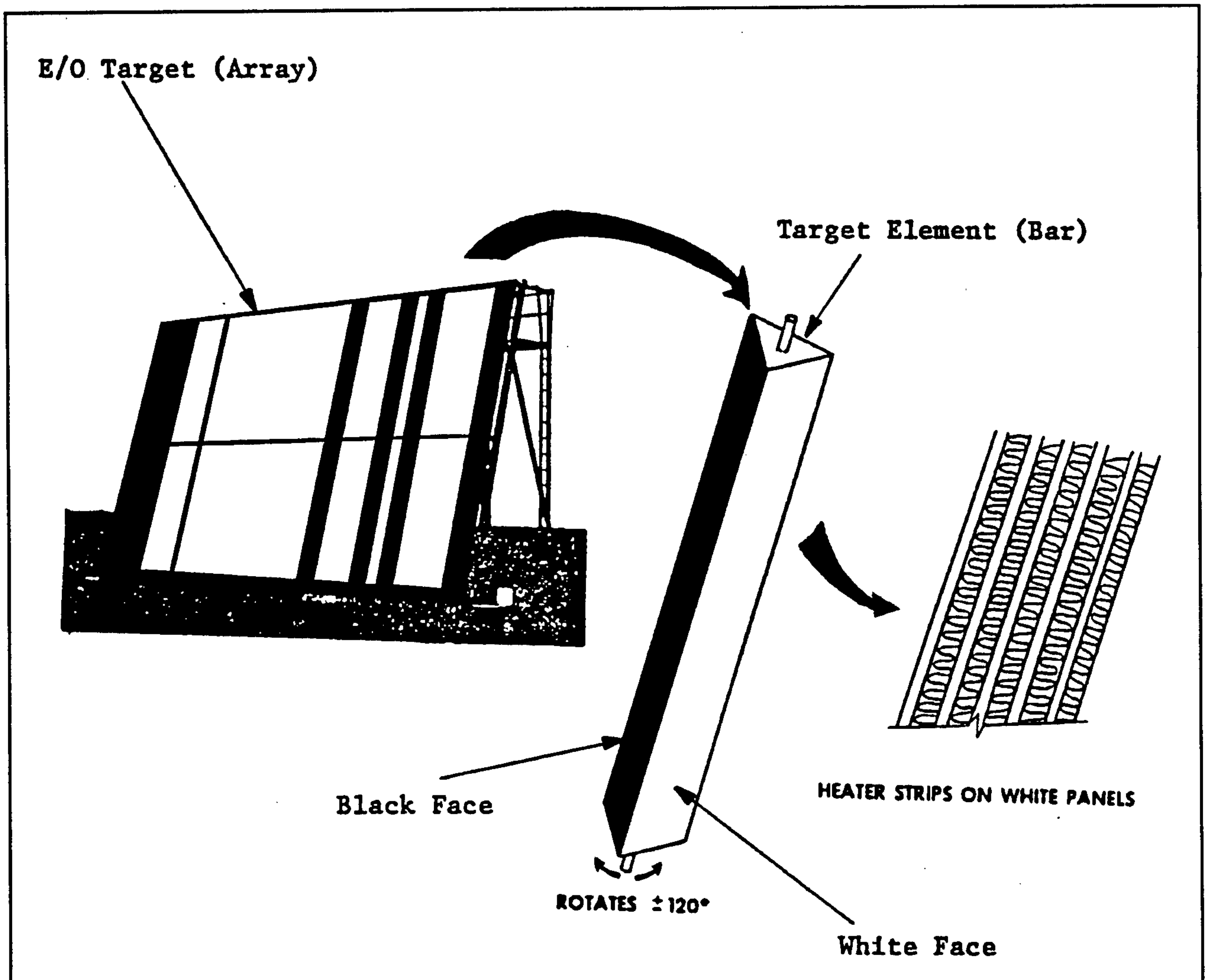
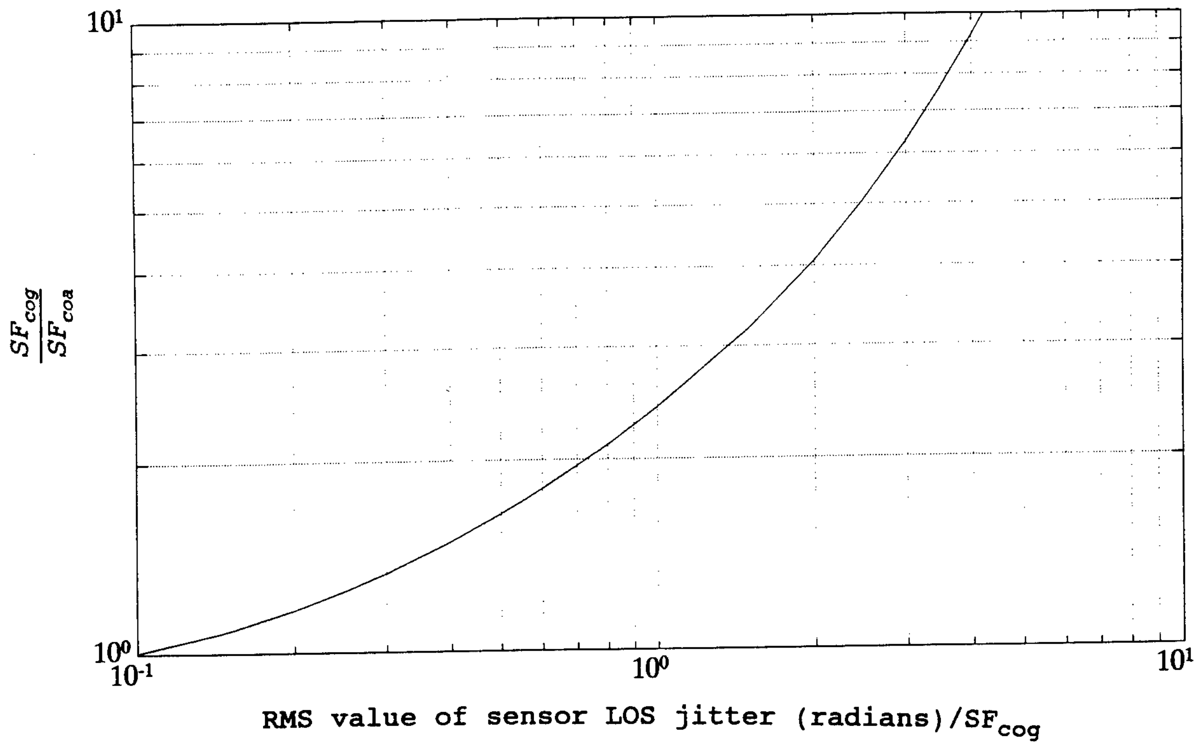


Figure 18: Sample Heated Ground Bar Target [Ref. 37: p.4.46b]

divided by airborne cutoff spatial frequency versus the root mean square (rms) value of the LOS jitter. [Ref. 37: p. 4.28b].

One important complication of the measurement of cutoff spatial frequency should be discussed. Three situations will be used as examples. In the first case, the target has a spatial frequency much lower than the cutoff spatial frequency of the FLIR. As the FLIR scans the bar target, the FLIR sees the hot and the cold bars with only short periods where the IFOV covers both. The response is shown in figure 20 part a. In the next case, the target spatial frequency is equal to the FLIR cutoff spatial frequency. In this case, the response, as shown in figure 20 part b is flat since the IFOV covers equal amounts of hot and cold bars. The third case is not as intuitively obvious. In this case, the target spatial frequency is slightly higher than the cutoff spatial frequency. As the FLIR scans over a cold bar, the FLIR sees the cold bar and in addition more than half of the hot bars on either side. The net effect is that the total appears hotter than the average of the hot and cold bars and the operator is shown the conflicting scene of hot bars where cold bars should be and cold where hot should be. Additionally, the apparent number of bars will be reduced. These effects are depicted in figure 20 part c and are theoretically repeated at multiples of the cutoff spatial frequency with corresponding reductions in the number of bars. Fortunately, the effect is rarely seen in application beyond the first interval. The effect is easily countered during tests by closely watching the targets and ensuring that data is taken at the first point where the response becomes level, as in figure 20 part b, and by watching the shape, polarity of the target (white or black bars) and number of bars. [Ref. 37: pp.



SF_{cog}=cutoff spatial frequency measured while airborne; includes LOS jitter (cycles/radian)

SF_{coa}=cutoff spatial frequency measured on the ground; does not include LOS jitter (cycles/radian)

Figure 19: Line of Sight Jitter [Ref. 37:p. 4.28b]

3.27-3.29b]. The test is performed in four parts. First a qualitative assessment is made of the FLIR to determine if the FLIR airborne minimum resolvable differential temperature and cutoff spatial frequency (angular resolution) are adequate for the mission. If not, the time and money must be spent to quantify the deficiencies. While on the ground, the collimator is used to determine a plot of resolvable differential temperature (RΔT) versus target spatial frequency (SF_t). The plot will by asymptotic on the vertical and horizontal axes as shown in figure 21 [Ref. 37: p. 4.28a]. The horizontal asymptote provides the ground MRΔT and the vertical asymptote provides the ground cutoff spatial frequency (SF_{∞}). During airborne testing, the airspeed versus spatial frequency response curve is first determined. A rough plot of the range when the bars become visible (not the false bars described earlier) versus airspeed can be plotted while airborne to determine the optimum airspeed. The evaluator may opt to merely use the normal ingress and attack speed for all further testing; however, in this procedure the optimum speed will be used. Next, the ground based bar target is used to determine the airborne values of RΔT versus SF_{∞}. These values are plotted coincident with the ground values as shown in figure 22 to determine airborne SF_{∞} and MRΔT. The airborne and ground MRΔT are theoretically the same. The difference in airborne and ground SF_{∞} ($SF_{\infty a}$, $SF_{\infty g}$)

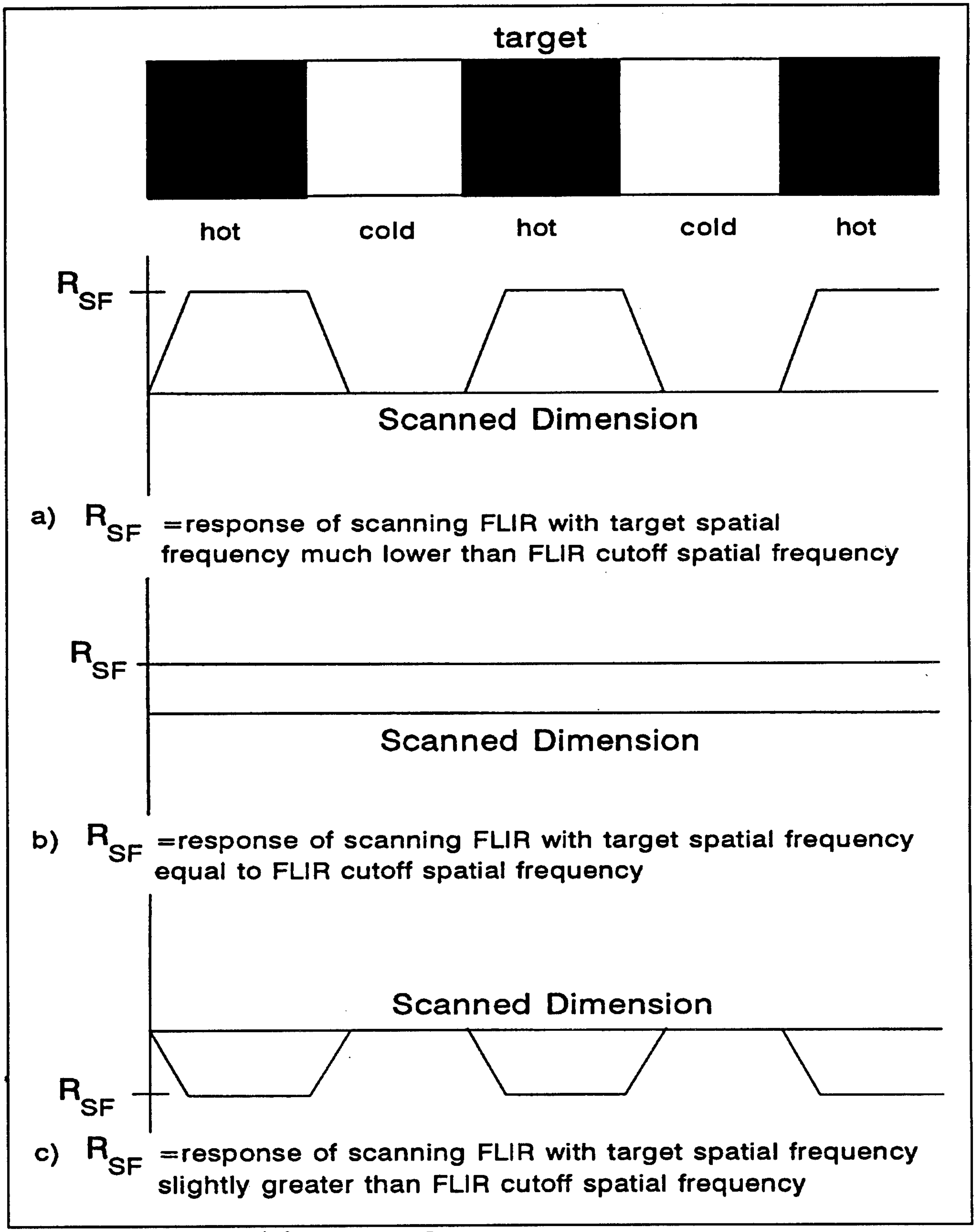


Figure 20: FLIR Spatial Frequency Response

are due to LOS jitter. As mentioned earlier, the rms value of LOS jitter is derived by entering figure 19 with the SF_{coa} and SF_{cog} values derived above. Equation 32 shows the relationship between the cutoff spatial frequency of the FLIR and the expected angular resolution. [Ref. 37: p. 4.26-4.28b].

$$r=\frac{1}{SF_{co}} \quad (32)$$

r=angular resolution of the FLIR
SF_{co}=cutoff spatial frequency

4.2.9.3.Instrumentation

Data cards and an optional voice recorder are required for the airborne qualitative portion of this test. A collimator with bar targets, radiometer, data cards and optional voice recorder are required for the ground test. A heated, ground based bar target, radiometer, ground based space positioning radar, data cards and optional voice recorder are required for the airborne range test.

4.2.9.4.Data Required

During the airborne qualitative test, record the ambient temperature, relative humidity and a complete description of any visible moisture or smoke in the test area including haze, fog, rain or clouds, along with the maximum and minimum cloud layer altitudes and visibility. Record qualitative comments concerning the visibility of objects close to the ambient temperature such as cold soaked aircraft and parked cars (static display airplanes and junk yards if you want to make sure they are cold soaked), abandoned buildings or trees. Record qualitative comments concerning the spatial resolution of hotter objects. The visibility of objects, cargo, hatches or even portholes on a steaming ship, the windows and doors on trucks or houses, even the shape of livestock in a field are possible indicators of spatial resolution (spatial frequency response). Qualitatively assess the utility of the FLIR MRΔT and spatial frequency response at a mission relatable airspeed for the assigned mission.

During the ground portion of the quantitative test, record the ambient temperature and relative humidity. Record the spatial frequency of each bar target used and the temperature differential at which the bars become indistinguishable. During the airborne portion of the quantitative test, record the ambient temperature, relative humidity and a complete description of any visible moisture or smoke in the test areas including haze, fog, rain or clouds along with the maximum and minimum cloud layer altitudes and visibility. With the target temperature set high, record the range at which the targets just become distinguishable for a range of airspeeds around the normal ingress and attack airspeeds. At the optimum airspeed, record the range at which the bars just become distinguishable, for decreasing temperature differentials.

4.2.9.5.Procedure

Prior to flying the qualitative portion of the test, select mission relatable targets near the minimum expected temperature differential. Additionally, select warmer mission relatable targets within the test area. Record the atmospheric conditions as listed above. Descend to a moderately low altitude of approximately 5,000 feet AGL and set a mission relatable ingress and attack airspeed. Qualitatively assess the utility of the FLIR for detecting and imaging the low ΔT targets and the detailed features of the warmer targets. If problems are noted during the qualitative tests perform the ground and airborne quantitative tests.

Before the ground quantitative test, record the atmospheric conditions as listed above. Check the contractor documentation and determine the theoretical cutoff spatial frequency. Select an initial bar target with a spatial frequency well below the expected cutoff spatial frequency. The spatial frequency of the targets can be determined using equation 30. Selection of the initial target and the interval for the next targets require some intuition of the expected cutoff spatial frequency and MRΔT. The technician that will undoubtedly come with the collimator may be helpful. The plot of RΔT versus spatial frequency should be plotted as the data is taken to allow feedback in the selection of bar targets. The plot should have enough data points at the correct intervals to ensure that the asymptotes and the curve are sufficiently defined. Starting at the lower spatial frequency, decrease the ΔT until the bars just become indistinguishable. Slowly raise the temperature until the bars just become distinguishable again and record the radiometer derived temperature. Ensure that the correct number of bars are present to show that the cutoff spatial frequency has not been exceeded. While data is taken, generate a rough RΔT versus spatial frequency plot and select the next bar target as described above.

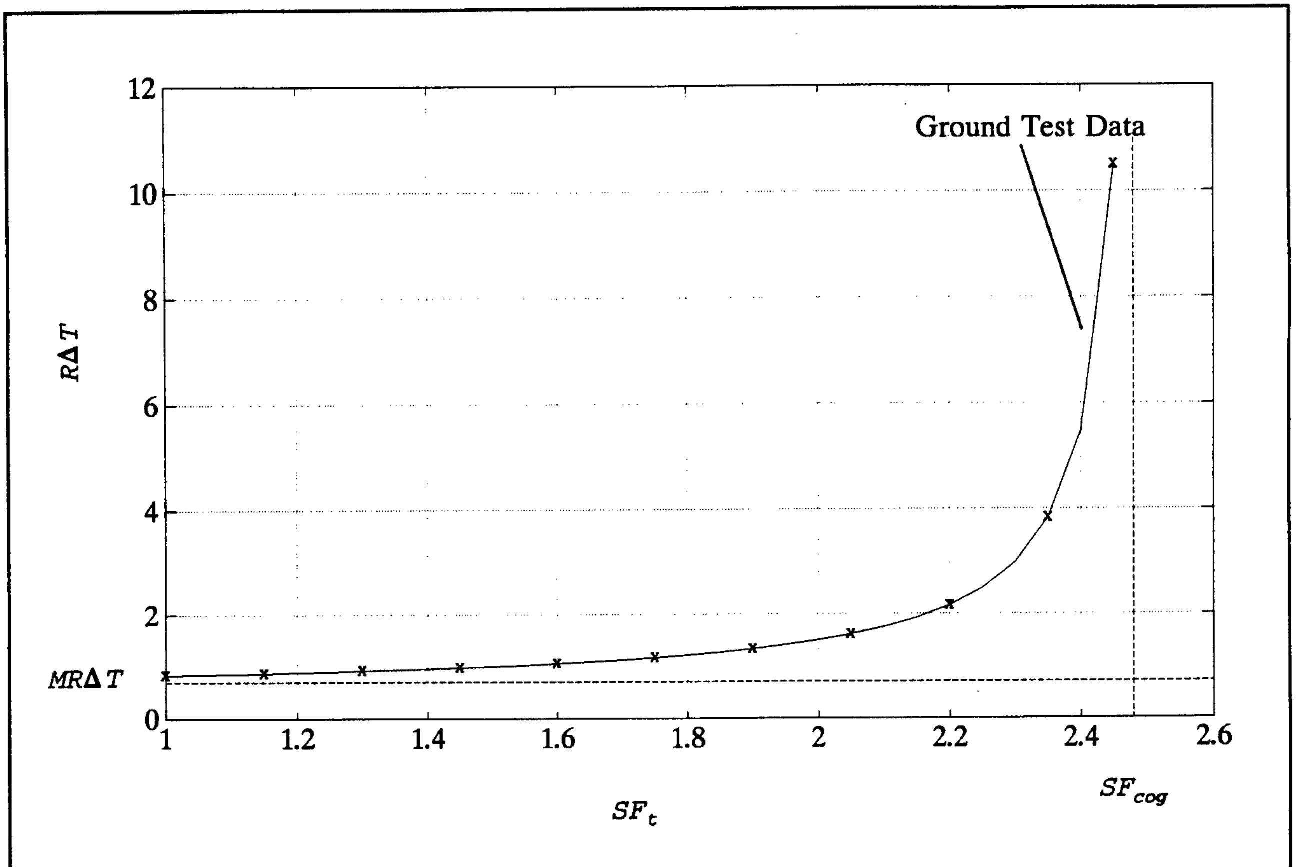


Figure 21: Ground Resolvable Differential Temperature Versus Spatial Frequency

Prior to the airborne quantitative test, record the atmospheric parameters listed above. Use the ground test data for the MRΔT value to determine a bar spacing that will allow for visibility of the target at beyond 5 nm. Choose a ΔT well above the MRΔT found during the ground testing. Choose visual cues to allow for rapid alignment with the line perpendicular to the target face at a range longer than the breakout range given the ground derived value of the cutoff spatial frequency.

Descend to the minimum altitude conducive to safe flight given the local terrain and obstruction features, the weather, performance characteristics of the airplane and qualifications of the pilot. Make the initial inbound run at an airspeed above the safe flying speed and well below the normal mission relatable ingress and attack speed. Call a mark on the radio at the point where breakout occurs and have the ground tracking engineer mark the aircraft to target range at that point. Take care to ensure that the correct number of bars are visible. Repeat at increasing airspeeds to the aircraft sealevel airspeed or Mach limit if possible and at the same ΔT and bar pattern. 50 KIAS intervals are usually sufficient. Generate a rough plot of the range versus airspeed. It may be helpful to have the ground based engineer marking the space positioning data to make the plot. The plot should peak at some airspeed value. The interval can be reduced to refine the peak value once a rough peak is found. Note that some aircraft generate a level curve. Perform the remainder of the airborne tests at an inbound airspeed equal to the peak airspeed found above or if the plot is level, at the expected mission relatable ingress and attack speeds.

During the next portion of the test, the target temperature is reduced and stabilized before each run. The data run is then made and the break-out range noted as above. A real time plot is made of the RΔT versus spatial frequency, as was done during the ground test. The plot should appear similar in shape to the ground derived plot except the vertical asymptote should be at a higher spatial frequency. The spatial frequency can be derived using equation 31. Adjust the target temperature to refine the curve and asymptotes as the

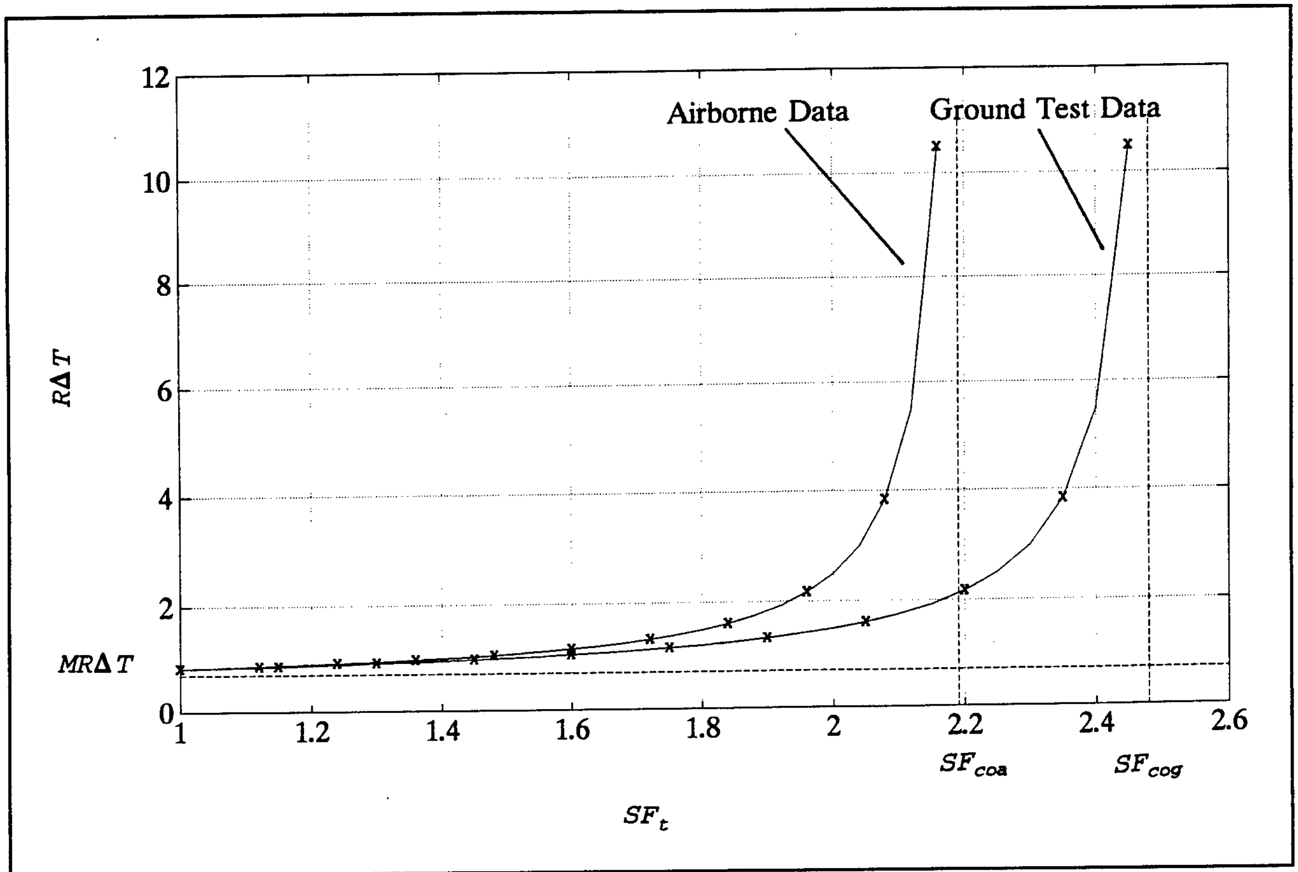


Figure 22: Airborne and Ground Resolvable Differential Temperature Versus Spatial Frequency

spatial frequency was used to refine the curve during the ground testing.

4.2.9.6. Data Analysis and Presentation

Relate the qualitative assessment of the MRΔT to the requirement to find and attack cold soaked targets of opportunity or cool operating targets. Relate the qualitative assessment of the cutoff spatial frequency to the requirement to identify small targets such as jeeps or trucks at a sufficient distance to allow set up and attack outside of shoulder fired surface to air missile range and to the requirement to view small details on targets as an aid in positive target identification in time for set up and attack outside of the expected defensive weapons range. Relate the observed atmospheric conditions to the expected mission relatable atmospheric conditions.

For the ground derived quantitative data, use equation 31 to derive the spatial frequency of the bar targets used. Plot the measured RΔT versus the spatial frequency of each target. The vertical asymptote defines the ground cutoff spatial frequency. The horizontal asymptote defines the MRΔT. For the airborne derived quantitative data, use equation 31 to derive the spatial frequency at the measured break out ranges. For the airspeed effects portion, plot the spatial frequency at breakout versus the airspeed. Relate the effects of airspeed on the FLIR spatial frequency response to the requirement to have flexibility in selecting airspeeds for navigation, ingress and attack. The optimum situation is to have a level plot over the entire range of expected operational airspeeds. The next best situation is to have the best response (the peak of the curve) over the most likely ingress and attack airspeed range. For the constant airspeed portion of the test, plot the RΔT versus the flight derived spatial frequency at breakout. Use the same plot used for the ground test results. Derive the asymptotic values of the MRΔT and airborne cutoff spatial frequency as from the ground test results. The MRΔT is theoretically identical. The airborne cutoff spatial frequency will theoretically be lower than the ground results due to jitter effects. Use the ground and flight cutoff spatial frequency results to enter figure 19 to determine the rms value of LOS jitter. Angular resolution can be derived from the ground and/or airborne cutoff spatial frequencies using equation 32. Use the results from the quantitative tests to back up the results found during the qualitative testing. Relate the observed atmospheric conditions to the expected mission relatable atmospheric conditions.

4.2.9.7.Data Cards

Sample data cards are provided as card 65.

CARD NUMBER ____TIME _____PRIORITY L/M/H

FLIR RESOLUTION (QUALITATIVE)

[DESCEND TO _____ FEET AGL, SET MACH=__. OPTIMIZE THE FLIR DISPLAY USING TARGETS OF OPPORTUNITY. SELECT THE GEOSTABILIZED REFERENCE MODE AND WHITE HOT OR COLD AS REQUIRED. RECORD QUALITATIVE COMMENTS, REPEAT AS TIME ALLOWS.]

AMBIENT TEMPERATURE _____

RELATIVE HUMIDITY _____

CLOUDS/VISIBILITY:

INITIAL POINT _______________

COOL TARGET DESCRIPTION:

QUALITATIVE COMMENTS:

INITIAL POINT _______________

COOL TARGET DESCRIPTION:

QUALITATIVE COMMENTS:

INITIAL POINT ______________

WARM TARGET DESCRIPTION:

QUALITATIVE COMMENTS:

INITIAL POINT ______________

WARM TARGET DESCRIPTION:

QUALITATIVE COMMENTS:

Card 65: FLIR Resolution Data Cards

CARD NUMBER _____

GROUND FLIR RESOLUTION (QUANTITATIVE)

AMBIENT TEMPERATURE _____

RELATIVE HUMIDITY _____

BAR SPACING	MEASURED RΔT

Card 65: FLIR Resolution Data Cards (Continued)

CARD NUMBER _____TIME _____PRIORITY L/M/H

AIRBORNE FLIR RESOLUTION AIRSPEED EFFECTS (QUANTITATIVE)

[DESCEND TO ___ FEET MSL AND SET ___ KIAS. PROCEED OVER THE IP TO THE TARGET. MARK THE BREAKOUT POINT. REPEAT AT INCREASING, 50 KIAS INTERVALS. REDUCE THE INTERVAL AS REQUIRED TO REFINE THE PEAK.]

AMBIENT TEMPERATURE _____

RELATIVE HUMIDITY _____

CLOUDS/VISIBILITY:

INITIAL POINT _______________

BAR TARGET LOCATION _______________

ΔT_____ BAR SPACING _____

AIRSPEED	RANGE

PEAK AIRSPEED _____

Card 65: FLIR Resolution Data Cards (Continued)

CARD NUMBER _____TIME _____PRIORITY L/M/H

AIRBORNE FLIR RESOLUTION AT CONSTANT AIRSPEED (QUANTITATIVE)

[DESCEND TO ___ FEET MSL AND SET ___ KIAS. PROCEED OVER THE IP TO THE TARGET. MARK THE BREAKOUT POINT. REPEAT AT DECREASING ΔT. ADJUST ΔT TO REFINE THE CURVE.]

AMBIENT TEMPERATURE _____

RELATIVE HUMIDITY _____

CLOUDS/VISIBILITY:

INITIAL POINT __________

BAR TARGET LOCATION __________

BAR SPACING _____

ΔT	RANGE

Card 65: FLIR Resolution Data Cards (Continued)